

Laboratory Protection Factor Tests of E.D. Bullard Company's Supplied-Air Respirators

J. H. King, Technical Director

E.D. Bullard Company, 1898 Safety Way, Cynthiaana, KY 41031-9303

Abstract

Simulated workplace protection factor (SWPF) studies conducted on continuous-flow class supplied-air respirators manufactured by E.D. Bullard Company yielded protection factors that exceeded the ANSI Z88.2-1992 minimum assigned protection factor of 1000. Eleven respirator models were evaluated on 12 test subjects using conventional quantitative fit testing practices. Subjects were tested while performing a series of exercises that simulated work activities. In all cases, results were higher than the minimum assigned protection factor of 25 stated in NIOSH's Respirator Decision Logic (RDL). Even after computing 5th percentile values and applying an order of magnitude safety factor, the results suggest that NIOSH's RDL may not accurately reflect the performance of Bullard's continuous-flow class respirators. Comparisons of hood-style and mask-style respirator performance, operated in a continuous flow mode, showed that hoods performed consistently across a range of airflow rates and worker activities. In contrast, mask performance varied considerably under similar conditions. These findings run counter to traditional thinking about the relative merits of hood- and mask-style respirators.

Introduction

The purpose of this study was to document the performance of E.D. Bullard Company's continuous-flow class supplied-air respirators. Such a study was necessary since some outside studies and the National Institute of Occupational Safety & Health (NIOSH) Respirator Decision Logic (RDL), (NIOSH RDL, 1987) have created questions about the performance of Bullard's continuous-flow respirators. Since Bullard produces more than one model of this class of supplied-air respirators, the study also compared the performance of different styles of respirators to determine how design might affect performance. A mask-style respirator was included for comparison and a combination mask/hood was added to assess the effect of the interface of these two types of respiratory inlet coverings

(RIC). Both of the mask-style respirators were operated in the continuous flow mode; no demand valves were used. Variation in airflow rate as it relates to respirator performance was studied as well.

Previous protection factor (PF) studies of Bullard's supplied-air abrasive blasting respirators show widely differing results (Blair, 1973; Douglas, 1976; Haggerty, 1990; King, 1991; Leighton, 1993; Samimi, 1975; Samimi, 1993; Skaggs, 1988; Sussel, 1992). Some of the results have contradicted Bullard's internal product evaluations. This may be attributed to poor work practices and/or improper testing methods. For example, in some studies the sampling tube was

positioned between the wearer's neck and the respirator neck seal, thus creating a leak path. Other studies measured respirator performance by placing sampling cassettes at the wearer's breathing zone and collecting contaminants during an entire work shift, even when the respirator was periodically removed during the observation period. Many researchers did not adequately assure that the manufacturer's instructions were followed during testing. Air supply pressures were not monitored and dirty respirator hoods were used during testing.

Bullard has conducted its own PF testing in actual workplace conditions and has engaged independent consultants to carry out further testing. Nonetheless, additional research is needed to properly characterize the performance of this class of respirators. Such additional research could also confirm the favorable performance measurements of the previous studies.

The RDL substantially downgraded two entire classes of respirators: continuous-flow and loose fitting hood-style respirators. NIOSH did this because there were no test requirements or procedures that properly measured the performance of these types of respirators. Since Bullard does not believe the RDL accurately reflects the performance of its own products, not to mention the downgraded class as a whole, the Company has undertaken several studies to quantify the performance of its products.

While the study presented here was conducted at E.D. Bullard Company facilities, the actual testing was directed and carried out by Occupational Health and Hygiene Corporation of America (OHHCA), an independent consulting firm headquartered in Downers Grove, Illinois.

Test Specimens

Eleven models of Bullard's supplied-air, continuous-flow respirators were evaluated; Table 1 lists the major characteristics of the models.

CC20 Series Supplied-Air Respirators

Four models of the CC20 Series were tested; each of these models has an inner collar that inflates to provide a body seal around the neck and a continuous flow of air to the breathing zone. These Type C hood-style respirators are designed for general industrial applications.

PC/CS90 Series Supplied-Air Respirator

The Bullard PC/CS90 Series containment suit (sample 5), developed primarily for the pharma-

ceutical industry, is a two-piece ensemble made of du Pont's Saran-coated Tyvek that is stitch-bonded for additional strength. The suit covers the wearer's body from the neck down; the parka-style hood covers the wearer's head, torso and arms. As air enters the hood, the inner collar or neck cuff inflates to help maintain positive pressure within the respirator hood. An inner bib tucks inside the suit so air discharged from the hood funnels into the suit. Air exhausts from the suit via four exhaust valves.

77 Series and 88 Series Supplied-Air Respirators

Bullard 77 (sample 6) and 88 (sample 7) Series respirators for abrasive blasting incorporate a hard outer shell which provides head protection

Model	Description
20T (sample 1)	Tyvek® hood with an inflatable neck cuff and a short outer bib.
20TIC (sample 2)	Similar to the 20T model but features a longer outer bib and an inner bib. The inner bib tucks inside the wearer's coveralls or workjacket. The outer bib drapes over the wearer's upper torso.
20NIC (sample 3)	Same as the 20TIC except the hood material is Nylon instead of Tyvek.
20TICH (sample 4)	Similar to the 20TIC but features a hard hat for head protection.

Table 1. Respirator characteristics.

Sample Number	1	2	3	4	5	6	7	8	9	10	11
Model	20T	20TIC	20NIC	20TICH	PC/CS9	77	88	1093	1095	BL/MT	M40
NIOSH TC Number (TC-19C-XXX)	154	154	154	154	280	84	293	229	229	***	202
Class	C	C	C	C	C	CE	CE	CE	CE	CE	C
Hood-style covering	X	X	X	X	X	X	X	X	X	X	
Mask-style covering										X	X
Soft-style hood	X	X	X	X	X			X	X	X	
Soft-style hood over mask										X	
Hard-style hood (helmet)						X	X				
Head protection available				X		X	X	X	X		
Inflatable neck cuff	X	X	X	X	X						
Elastomeric face seal flange										X	X
Knitted neck cuff						X	X	X	X		
Outer bib or cape	X	X	X	X	X	X	X	X	X	X	
Inner bib		X	X	X	X				X		
Minimum flow (l/m) *	170	170	170	170	170	170	170	170	170	115	115
Normal flow (l/m) **	225	225	225	225	225	225	225	225	225	170	170

* Minimum flow refers to the NIOSH minimum flow required for continuous flow class respirators.

** Normal flow refers to the target flow obtained when E.D. Bullard Company pressure schedules are used at the point-of-attachment to the air-line respirator.

*** Note that the Blast Mate respirator is NIOSH approved as both a continuous flow class type C and CE device and a pressure demand class type C and CE device. Even though NIOSH has granted the respirator a pressure demand approval it is operated in the continuous flow mode. The NIOSH TC number for the continuous flow approval is TC-19C-271. The NIOSH TC number for the pressure demand approval is TC-19C-291.

per the American National Standards Institute (ANSI) standard Z89.1-1969 (ANSI Z89.1, 1969). The products also feature double lenses, knitted elastic neck cuff, and an outer bib in the form of a cape.

The 77 Model has an air distribution plenum near the wearer's forehead. Relatively high pressure air (about one atmosphere) is forced through the permeable membrane of the plenum and expelled into the interior of the hood. In contrast, relatively low pressure air (less than 1/10 atmosphere) enters the 88 hood and is channeled between the inner and outer helmet shell before entering the interior of the hood via an opening at the wearer's forehead.

1090 Series Supplied-Air Respirators

The Bullard 1090 Series respirators are more durable than the CC20 Series since they contain a lens housing that holds replaceable lenses, and include a Nylon fabric hood. Like the 20TICH, provision is made for a conventional industrial

class B hard hat. Also like the CC20 Series, air is introduced into the hood via an inflatable neck cuff. In addition to the inflatable neck cuff, the 1090 Series hood also incorporates a knitted elastic neck cuff similar to that in the 77 and 88. The model 1093 (sample 8) hood, typically used for painting, is made of nylon sail cloth and contains a short, loose fitting outer bib. The model 1095 (sample 9) hood, typically used for light duty abrasive blasting, is made of urethane coated nylon and includes a long outer cape designed to cover the wearer's torso.

M40 Series Supplied-Air Respirators

The M40 full face mask-style respirator (sample 11) incorporates a tight fitting neoprene rubber mask with a single face sealing flange. One exhalation valve is used. The mask is available in only one size.

Blast Mate Supplied-Air Respirators

The Blast Mate (BL/MT) respirator (sample 10) uses the same mask as the M40 respirator;

however, it is modified with a special lens housing that accommodates multiple abrasive blasting lenses. Additionally, there are two exhalation valves instead of one, with porous foam filters between the valve bodies and snap-on covers. The foam reduces noise caused by the flow of air exhausting through the valves. This is required since NIOSH places limitations on the amount of

noise a hood-style respirator can generate. A loose fitting, cape-style hood fits over the mask and the wearer's head, neck and torso. The hood/cape contains a rubberized abrasive blasting shield in the wearer's facial area which attaches to the mask's lens housing. The hood includes a knitted neck cuff similar to the 77, 88 and 1090 Series respirators.

Preparation of Test Specimens

All sample respirators were fitted with miniature plastic quick disconnects and "O" ring seals for breathing zone sampling. The female portion of the 1/8" ID plastic couplings was cemented into drilled holes in the hood or mask lenses so that the inlet to the couplings was in the wearer's breathing zone. In cases involving multiple lenses, the

quick disconnect coupling was mounted to the side of the lens or in the side of the respiratory inlet covering (mask or hood). In these cases a short piece of 1/8" ID plastic tubing was used on the inside of the RIC. Then, one end of the tubing was attached to the inlet of the coupling and the other end positioned in the wearer's breathing zone.

Test Panel

The test panel was comprised of 12 Bullard employees: six men and six women. A concerted effort was made to use test subjects with facial sizes that represented each box of the Los Alamos Scientific Laboratory (LASL) panel for testing full facepiece respirators (Held, 1974); however, extremely small faces were not available. Table 2 indicates facial sizes of the 12 subjects; the smaller faces tended to be female. Ten panelists were

given spirometry tests at a local hospital after the PF testing was completed. Two subjects were unavailable for spirometry testing since their term of employment expired before this phase of testing. Table 2 lists vital capacity and peak inspiratory flow rate data for the 10 panelists for which spirometry data exist. This data shows that female panelists generally exhibited lower peak inspiratory flow rates than males.

Table 2. Test panel characteristics.

Test Panel Subject	Sex	Face Width (mm)	Face Length (mm)	Peak Inspiratory Flow (l/m)	Vital Capacity (liters)
A	F	118	116	n/a	n/a
B	M	145	129	237	4.25
C	F	122	111	218	4.80
D	F	127	117	243	4.06
E	F	128	106	200	3.59
F	F	123	104	229	2.98
G	F	134	116	420	4.79
H	M	138	124	362	4.73
I	M	148	117	451	4.87
J	M	137	111	n/a	n/a
K	M	134	122	460	6.85
L	M	122	109	362	5.15

n/a data not available.

Test Equipment

Testing was carried out using the Model TDA-50 aerosol generator and detection instrument, a quantitative aerosol tester from Air Techniques Incorporated (ATI). This device uses forward light scattering photometry to measure aerosol concentration and a controlled corn oil or mineral oil aerosol as the test agent. The TDA-50 aerosol generator, a Laskin nozzle type, produces an aerosol with a light scattering mean geometric diameter of 0.70 microns with a range of 0.3 to 3 microns. The product of the generator was diluted with filtered air to obtain a concentration range of 10 to 100 micrograms/liter. Mineral oil was used as the test agent in an ATI Model 70 test chamber modified for use with supplied-air respirators. The detection system determines the concentration of aerosol, which serves as a base line, and reads out linearly the percent of penetration into the respirator down to 0.001% (PF read-

ings up to 100,000). Readings were plotted continuously on a strip chart recorder throughout an entire test set. The detection system sampling airflow rate was set at about 6 liters/minute (l/m).

A manifold was fitted inside the test chamber to supply breathing air to the respirators worn by test panelists. A short length of airline hose was attached to the manifold and fitted with a quick disconnect at the free end so that test subjects could easily connect the respirator breathing tube to the air supply source. The manifold was supplied with compressed air from outside the chamber. Supplied air was filtered and regulated with a Bullard 41P6 Airline filter before passing through a Hastings Teledyne mass flow meter with a capacity of 566 l/m. The mass flow meter was used to monitor and maintain the desired airflow to the test respirator.

Test Procedures

From July 6 through September 16, 1992, OHHCA conducted PF testing at the Cynthiana, Kentucky manufacturing facility of E.D. Bullard Company. Testing was directed by a Certified Industrial Hygienist (CIH) and conducted by OHHCA personnel.

Subjects were tested using conventional quantitative fit testing practices. The test chamber and physical exercise regime were adjusted for the evaluation of continuous-flow supplied-air respirators. Each subject was tested while performing a series of physical exercises that simulated work activities or activities such as jogging in place that were thought to be more strenuous than normal work activities. The test chamber does not duplicate all possible work conditions such as abrasive blasting where high velocity abrasive rebound is present. However, the jogging in place exercise creates a jarring action that tends to dislodge the RIC, making it more difficult for the respirator to perform well. The exercise regime consisted of the consecutive performance of each selected physical exercise for four minutes. The physical exercise regime consisted of the following activities: normal breathing (start), deep breathing, side-to-side head movement, toe touches, jogging in place, and normal breathing (end).

In addition to initial and final zero base line checks, instrument calibration checks were per-

formed after every two exercises. If the penetration measurement consistently remained below 0.01%, then the duration of the exercise was reduced to three minutes since little variation in aerosol penetration was evident.

Test panelists were familiarized and trained in the use of the respirators by an industrial hygienist before entering the test chamber. Subjects were tested using each of the eleven sample respirators. Tests were conducted at two airflow rates: minimum flow (115 l/m for masks and 170 l/m for hoods) and normal flow (170 l/m for masks and 225 l/m for hoods). Minimum flow is the established NIOSH respirator certification requirement (NIOSH 30 CFR 11, 1972) for the minimum supplied air flow rate. During the testing the airflow into the test respirator was continuously monitored by the hygienist to assure that it did not vary from the pre-established set point. The airflow rate was maintained within 3 l/m of the selected value.

After the test subject donned the RIC and entered the test chamber, he/she connected the quick disconnect at the end of the breathing tube to the air supply line attached to the air supply manifold. Then the quick disconnect fitting on the end of the respirator sampling probe was connected to the fitting mounted into the RIC. When the mineral oil aerosol concentration in the test

chamber reached equilibrium, the test subject began the exercise regime while the aerosol penetration into the RIC was recorded continuously on a strip chart recorder. When testing was completed at the minimum airflow rate, the flow

was increased to the normal level and the equilibration period repeated to compensate for the greater dilution rate within the test chamber. After equilibrium was re-established the exercise regime was repeated.

Data Reduction

The strip chart recording for each exercise was used to measure the average and peak penetration in percent. The peak penetration (P_i) was indicated as the highest reading on the chart. The average penetration was determined by using a compensating polar planimeter to determine the relative area under the curve. This area was then divided by the test exercise duration to obtain the time weighted average penetration (A_i) for the exercise in percent. Therefore six P_i s and six A_i s were determined for the six exercises of a given test set. A master test data matrix was generated from these data. An example of the matrix, shown in Figure 1, illustrates the methods of calculation used to complete the matrix.

The six P_i s were averaged arithmetically to obtain the mean peak penetration (PK) for the entire test set of six exercises. The PK was then used to compute the peak penetration protection factor (PKP) for the test set.

Likewise, the six A_i s were averaged arithmetically to obtain the time weighted average penetration (AV) for the entire test set of six exercises. The AV was then used to compute the time weighted average (TWA) protection factor for the test set.

Using the PKPs and TWAs associated with each test subject (A through L) a statistical analysis was performed for each respirator evaluated at two airflow settings (minimum flow and normal flow). Using a Pearson coefficient of skewness test the data generally appeared to be log normally distributed. Log normal distribution transformations were used for this analysis. Log normal means, standard deviations, and 5th percentile values were calculated for each respirator at the

two airflow rates for both PKP and TWA PFs. This resulted in the four sets of data shown in Table 3.

Edwin C. Hyatt, CIH, (Hyatt, 1984) has proposed that workplace PFs could be conservatively estimated as one tenth (1/10) of the PFs obtained in the laboratory. Therefore, the results presented in Table 3 include this safety factor as a set of values which are 1/10th of the 5th percentile TWA PFs. From this table values were plotted for minimum flow TWA PFs. Geometric means, 5th percentile and 1/10th of the 5th percentile PFs for each respirator evaluated are shown in Figure 2 to illustrate the relative difference.

As seen in Table 2, respirator wearers with a greater vital pulmonary capacity are likely to exhibit higher peak inspiratory flow rates during high stress activities such as jogging than wearers who have lower vital pulmonary capacity. To determine the effect on respirator performance associated with peak inspiratory flow rate, the data were analyzed for typical mask-style and hood-style RICs. TWA PFs obtained from the ten test subjects for which spirometry data was available were plotted against their reported peak inspiratory flow rates. These plots, involving the 77 hood-style and M40 mask-style RICs, are presented in Figure 3.

The results of the jogging in place exercise were compared to those obtained from the initial normal breathing exercise. The TWA PFs associated solely with jogging and normal breathing are shown in Figure 4. Fifth percentile TWA PFs associated with minimum air flow and normal air flow supplied to the respirators are shown in Figure 5.

Analysis of Results

Since respiratory protection is based, in principle, upon time weighted average exposure to contaminants TWA PFs are the best predictor of overall respirator performance. Time weighted average PFs obtained with minimum air flow are

presented in Figure 2. These data demonstrate that the PC/CS90, 77 and 88 respirators (samples 5,6,7) provided the highest TWA PFs. The 20T and 1090 series respirators (samples 1,8,9) provided the lowest TWA PFs.

Figure 1. Methods of data reduction.

Example Data Matrix					
20T RESPIRATOR					
TEST SUBJECT	TEST EXERCISE	AVG PEN (%)	AVG PF	PEAK PEN (%)	MIN PF
A	NORM BREATHING	A1	AP1	P1	PP1
A	DEEP BREATHING	A2	AP2	P2	PP2
A	SIDE TO SIDE	A3	AP3	P3	PP3
A	TOUCHING TOES	A4	AP4	P4	PP4
A	JOGGING	A5	AP5	P5	PP5
A	NORM BREATHING	A6	AP6	P6	PP6
A	AVERAGE	AV	TWA	PK	PKP

TYPICAL CALCULATIONS

$$AV = (A1 + A2 + A3 + A4 + A5 + A6) / 6$$

$$PK = (P1 + P2 + P3 + P4 + P5 + P6) / 6$$

$$TWA = (1/AV) \times (100\%)$$

$$PKP = (1/PK) \times (100\%)$$

$$APi = (1/Ai) \times (100\%)$$

$$PPI = (1/Pi) \times (100\%)$$

Ai = Time weighted average penetration (area under curve divided by time) for a given test exercise.

Pi = Peak penetration or maximum penetration value during a given test exercise.

APi = Time weighted average protection factor for a given test exercise.

PPI = Protection factor calculated from the peak penetration obtained during a given test exercise.

AV = **Arithmetic** average of the six average test exercise penetrations of a test set.

PK = **Arithmetic** average of the six peak test exercise **penetration** values of a test set.

TWA = Time weighted average protection factor for a given test set.

PKP = Peak penetration protection factor for a given test **set**.

Strip Chart Recording for a given test exercise.

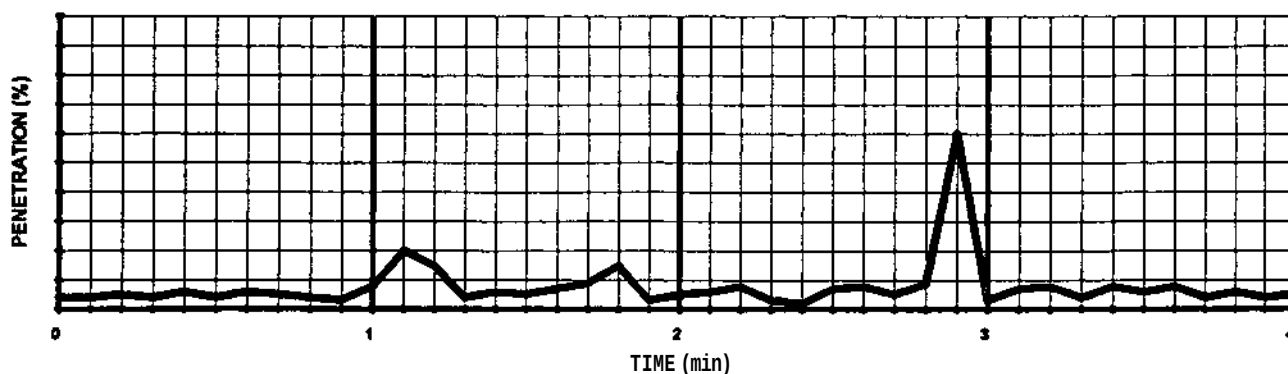


Table 3. Summary of log normal statistics.

Model	Hood styles									Mask styles	
	20T	20TIC	20NIC	20TICH	PC/CS90	77	88	1093	1095	BL/MT	M40
	General use and paint				Pharm	Abrasive blasting				Paint	
I/m	170	170	170	170	170	170	170	170	170	115	115
MEAN	25374	42140	41341	43221	55242	58653	55593	26897	33053	38168	47717
MEDIAN	25344	46846	48867	47022	58540	60618	54676	27522	42005	43119	48997
STD DEV	2.19	1.63	1.62	1.71	1.29	1.15	1.3	2.05	2.17	1.77	1.41
5thX	7004	18942	18637	17911	37334	46626	36221	8246	9262	14886	27089
5th/10	700	1894	1864	1791	3733	4663	3622	825	926	1489	2709
I/m	225	225	225	225	225	225	225	225	225	170	170
MEAN	28333	46482	42932	46540	60494	58340	61047	28999	40387	51254	59862
MEDIAN	27930	49816	47073	51975	61145	56856	55639	36835	46822	50407	63352
STD DEV	1.88	1.64	1.71	1.57	1.23	1.2	1.3	2.12	1.9	1.47	1.39
5thX	9987	20501	17843	22072	42833	43471	40693	8457	14057	27090	34633
5th/10	999	2050	1784	2207	4283	4347	4069	846	1406	2709	3463
Sample	1	2	3	4	5	6	7	8	9	10	11
I/m	170	170	170	170	170	170	170	170	170	115	115
MEAN	3103	15303	19090	16914	19921	31215	35571	5489	8983	6396	11555
MEDIAN	2139	21395	22031	18483	18689	32041	34786	5428	10121	4103	14317
STD DEV	4.14	2.08	1.96	2.31	1.77	1.45	1.42	2.99	3.68	4.85	3.44
5thX	299	4775	6334	4278	7760	16983	19867	907	1056	470	1515
I/m	225	225	225	225	225	225	225	225	225	170	170
MEAN	5628	18014	17643	14880	25265	40197	34271	7869	14949	22987	35653
MEDIAN	6358	21477	26305	23725	31553	40920	31907	10542	15496	32705	41318
STD DEV	3.49	1.97	2.27	2.95	1.82	1.3	1.55	3.2	2.88	2.96	2.03
5thX	720	5919	4578	2517	9419	26161	16628	1164	2617	3864	11137
Model	Hood styles									Mask styles	
	20T	20TIC	20NIC	20TICH	PC/CS90	77	88	1093	1095	BL/MT	M40
	General use and paint				Pharm	Abrasive blasting				Paint	

With the exception of the 20T, the CC20 Series respirators (samples 1-4) performed well exhibiting 5th percentile TWA PFs of 18000-22000. By contrast, the 20T exhibited a 5th percentile TWA PF of only 7000. The absence of an inner bib is what primarily differentiates the 20T from the other CC20 Series respirators. The inner bib tucks into the wearer's work clothing and thus creates a better, more positive seal against the wearer's body. In addition to having an inner bib, the PC/CS90 containment suit hood (sample 5) is constructed as a parka and thus forms a double body sealing barrier. Consequently the PC/CS90 containment suit respirator exhibited high 5th percentile TWA PFs of 37000-43000.

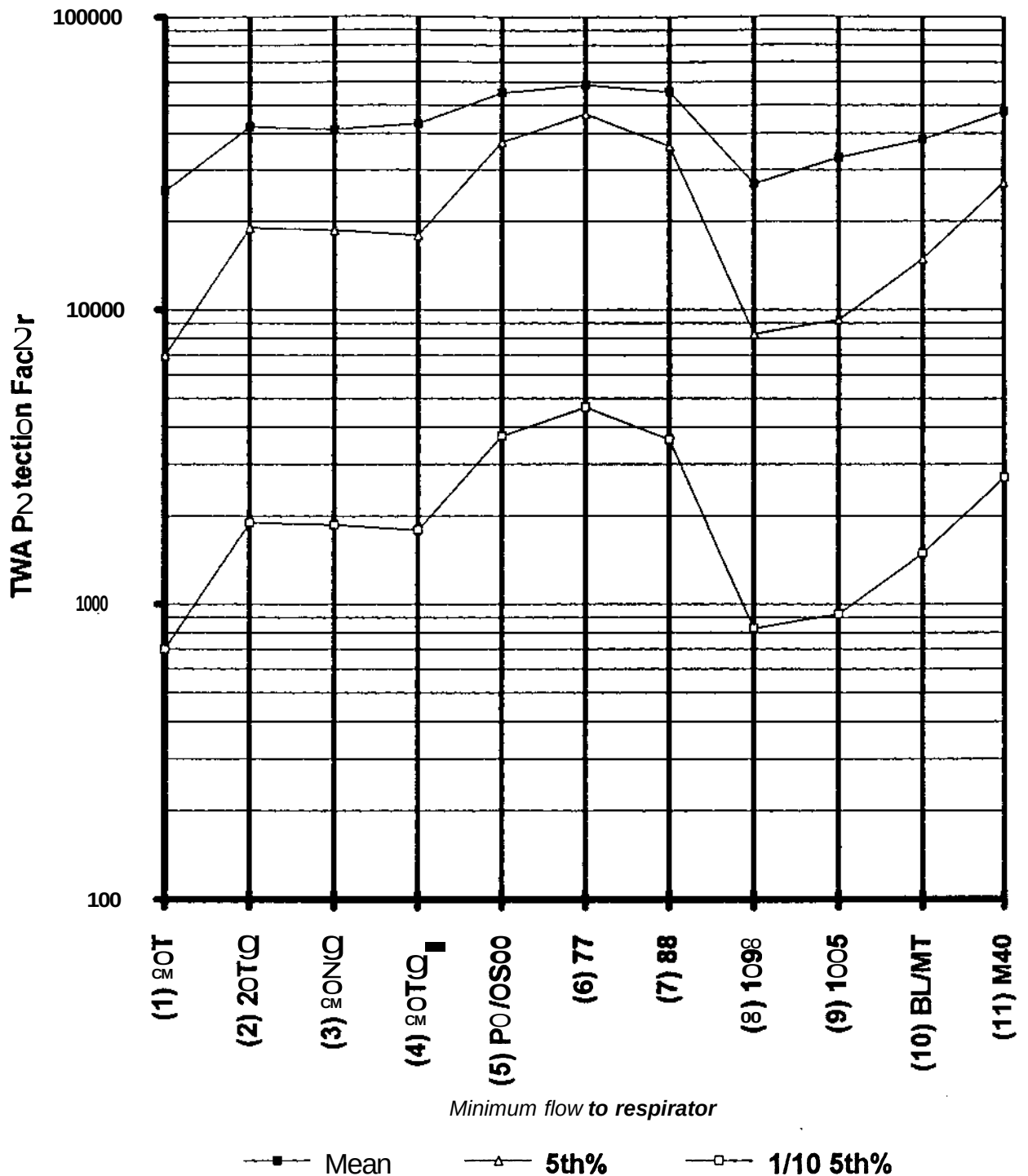
The 77 and 88 model hoods (samples 6 & 7) incorporate a knitted neck cuff to form the seal against the body. This cuff material is porous and thus exhausted air seeps or bleeds through the

material. The 88 is similar to the 77 except the air distribution system inside the 88 hood allows air to flow at a relatively high velocity into the breathing zone. The 88 Series users have indicated they prefer the feel of airflow in the hood as opposed to the air bleeding through a permeable membrane air distribution plenum as incorporated in the 77 respirator hood. The 77 and 88 respirators exhibited 5th percentile TWA PFs of 36000-47000.

The 1090 Series respirators (samples 8 & 9) also use knitted neck cuffs to seal against the wearer's body and yet the two respirators tested performed at about the same level as the 20T. The main difference is that the lens is loosely fitted into the hood for easy replacement purposes.

Overall, the M40 full face mask (sample 11) performed well, yielding 5th percentile TWA PFs of 27000-35000. However, as Figure 3 illustrates,

Figure 2. Summary of time weighted average protection factors.



Legend

1. Samples 1-5 are Type C, Hood style respirators operated at 170 l/m air flow.
2. Samples 6-9 are Type CE, Hood style respirators operated at 170 l/m air flow.
3. Sample 10 is a Type CE, full facepiece Mask style respirator operated at 115 l/m air flow.
4. Sample 11 is a Type C, full facepiece Mask respirator operated at 115 l/m air flow.

Fig 1 **3** Breathing capacity vs self-determined respirator protection factors.

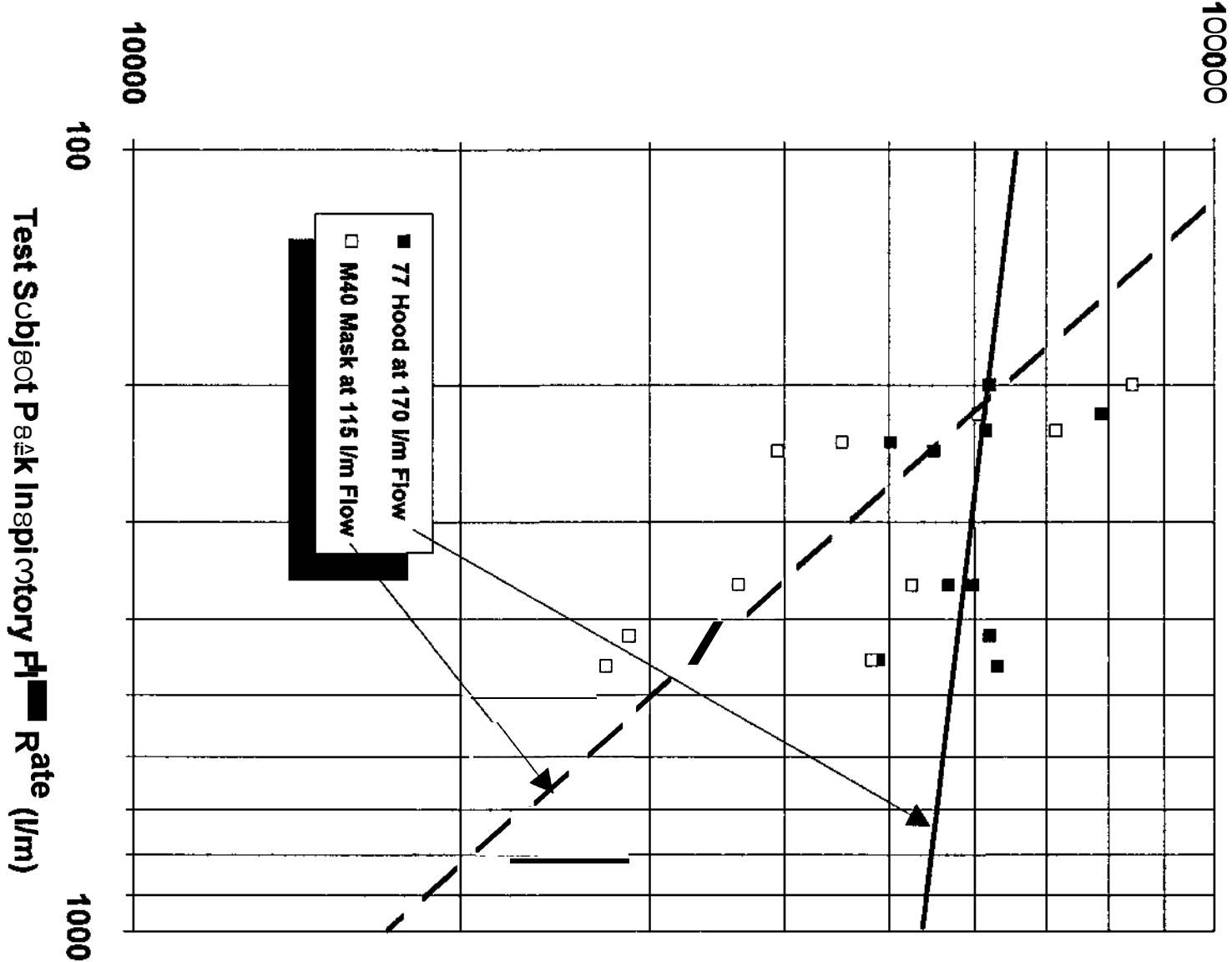
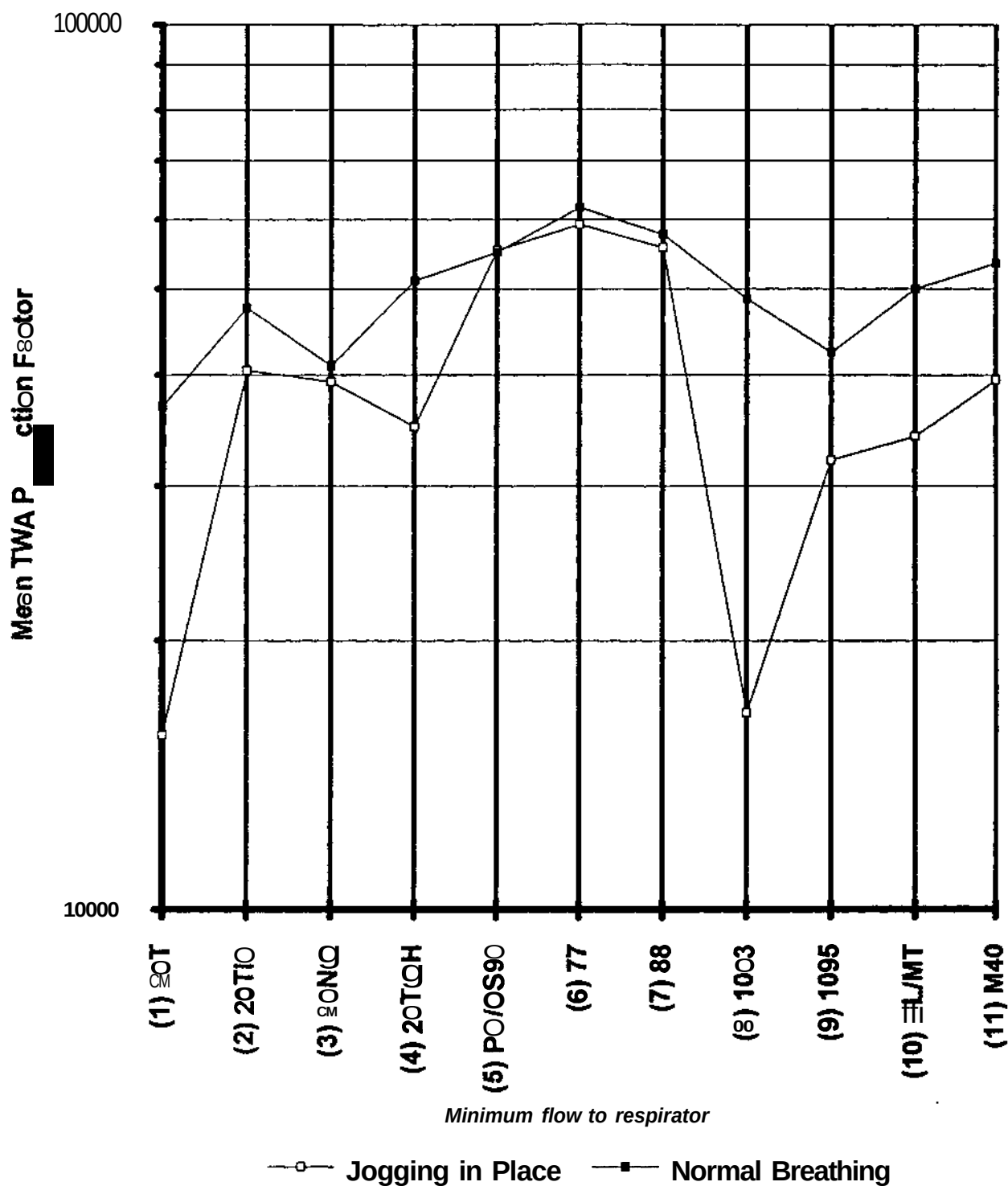


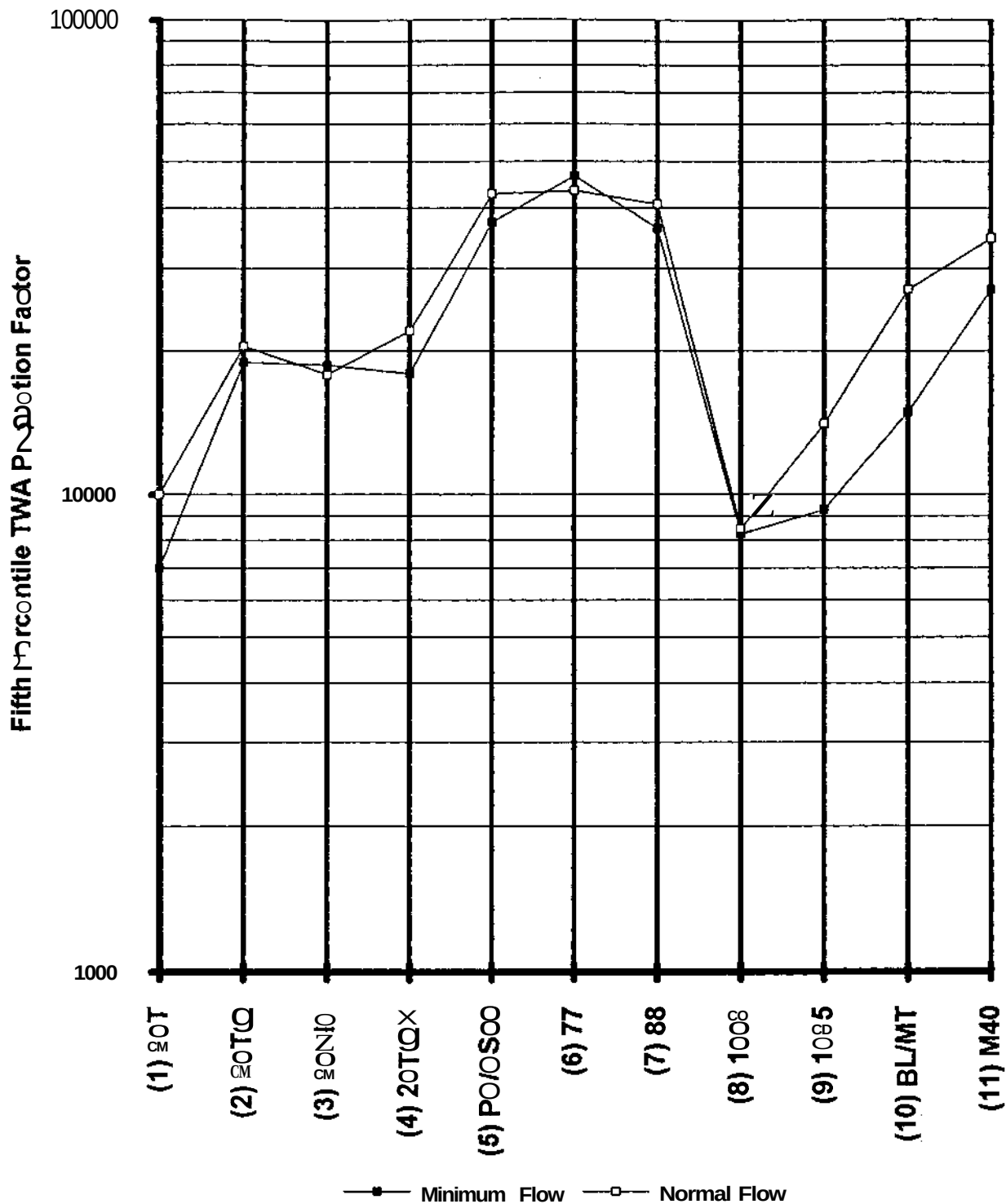
Figure 4. Normal breathing vs jogging in place protection factors.



Legend

1. Samples 1-5 are Type C, Hood style respirators operated at 170 l/min air flow.
2. Samples 6-9 are Type CE, Hood style respirators operated at 170 l/min air flow.
3. Sample 10 is a Type CE, full facepiece Mask style respirator operated at 115 l/min air flow.
4. Sample 11 is a Type C, full facepiece Mask style respirator operated at 115 l/min air flow.

Figure 5. Fifth percentile time weighted average protection factors.

**Legend**

1. Samples 1-5 are Type C, Hood style respirators operated at 170 & 225 Lm air flow.
2. Samples 6-9 are Type CE, Hood style respirators operated at 170 & 225 Lm air flow.
3. Sample 10 is a Type CE, full facepiece Mask style respirator operated at 115 & 170 Lm air flow.
4. Sample 11 is a Type C, full facepiece Mask style respirator operated at 115 & 170 Lm air flow.

the mask is more susceptible to over-breathing than hoods like the 77 and 88. The Blast Mate respirator (sample 10) does not perform as well as the M40 even though it uses the same mask as the M40. The abrasive blasting hood/cape that fits over the mask may account for this. Contaminated air that is trapped under the hood and cape may not get adequately flushed by air exhausting from the mask. Thus the aerosol concentration in close proximity to the mask may reach higher levels than in the outside ambient environment.

It is interesting to note that the difference in mean TWA PFs obtained between the normal breathing and jogging in place exercises appears to relate to overall respirator performance. According to Figure 4, the highest performing respirators (samples 5,6,7) exhibited little difference in performance between normal breathing and jogging. Relatively large differences in performance between normal breathing and jogging were exhibited by those respirators incorporating hard hats (samples 4,8,9). This may have to do with the tendency of the head protective device to bounce around inside the hood and thus causing the RIC to dislodge and interfere with the neck seal.

Performance may have been improved if the optional hard hat chin straps had been used.

Excluding the lowest performing respirators (samples 1,8,9), Figure 5 illustrates that the remaining hood-style respirators exhibited less difference in performance between minimum and normal air flow rates than the mask-style respirators. All of the above results may not apply to other models and brands of respirators belonging to the same class as those studied here.

Since the 5th percentile TWA PFs were obtained from laboratory tests, they should be reduced by a factor of ten (Hyatt, 1984). It is interesting to compare these 1/10th 5th percentile TWA values to the 5th percentile PKP PF values. With the exception of the 20T and the mask-style respirators, the factored (1/10th 5th percentile TWA) values are less (more conservative) than the 5th percentile PKP PFs. Since the factored values are based on time weighted average results they are also more statistically valid due to averaging.

Based on the 1/10th 5th percentile TWA PF values, Bullard conservatively rates its respirators as follows:

MODEL	TYPE	ASSIGNED PF
20T	HOOD	500
20TIC	HOOD	1500
20NIC	HOOD	1500
20TICH	HOOD	1500
PC/CS90	HOOD	3500
77	HOOD	3500
88	HOOD	3500
1093	HOOD	500
1095	HOOD	500
BL/MT	MASK	1500
M40	MASK	2500

Conclusions

- All respirators tested yielded 5th percentile TWA PFs greater than the ANSI standard Z88.2-1992 (ANSI Z88.2, 1992) minimum assigned PF of 1000.
- Respirator wearers who have a capacity to breathe deeply may obtain less protection during high physical stress activities.
- High levels of physical stress generally result in lower protection factors as indicated by comparing data from jogging in place to normal breathing.
- The way a loose fitting hood interfaces with the wearer's body (body seal) can greatly affect the respirator's performance. This interface may be more important than the amount of airflow into the respirator (170 l/m or 225 l/m).
- If a loose fitting covering is placed over a tight fitting mask, the effectiveness of the mask may be reduced.
- Loose fitting hoods can perform better than tight fitting masks depending upon the design of the hood's body seal.

Comments

There is presently a great deal of conflicting information that confuses and concerns respirator researchers, manufacturers, hygienists, and users about the protection afforded by different classes of respirators. Nowhere is the confusion more pronounced than in the case of continuous-flow class, supplied-air hood-style respirators. NIOSH's RDL recommends a minimum assigned PF of 25, while the ANSI standard Z88.2-1992 recommends 1000. The NIOSH recommendations are beginning to become reflected in actual workplace regulations. Users of continuous-flow supplied-air hood-style respirators now wonder why there has been such a dramatic derating of a protective device which has been used successfully for years. The results of the present study suggest, at least for users of Bullard respirators, that the downgrading of the PFs is unwarranted. The results support work that led to the ANSI standard Z88.2-1992 recommendations.

This study also has interesting implications for researchers and manufacturers of respiratory protection devices. Conventional beliefs about the performance superiority of a tight fitting mask compared to a loose fitting hood may be inaccurate. The performance of several Bullard hood-style respirators was similar at the NIOSH certification minimum requirement of 170 l/m as well as at the higher 225 l/m of airflow. In contrast, the performance of the mask-style respirators was noticeably less at the NIOSH required minimum of 115 l/m than it was at 170 l/m. Furthermore, while high levels of physical stress generally result in lower PFs, as indicated by comparing data from jogging in place to normal breathing, the reduction in PFs

was less with the 20TIC, 20NIC, PC/CS90, 77 and 88 Series hood-style respirators than it was with the mask-style respirators. This difference may, in part, be attributable to the larger internal volume afforded by hoods and becomes even greater when the design of the respirator's body seal is taken into account.

With respect to the hood-style respirators themselves, there was a difference in performance among the Bullard models evaluated. Design of the interface between the respirator and the wearer's body (body seal) appears to have an important effect on respirator performance for hood-style respirators. The design of the body seal appears to be more important in terms of respiratory protection than the amount of airflow into the respirator, at least within the airflow range of 170 l/m to 225 l/m. Inflatable neck cuffs or knitted neck cuffs provide a good body seal which can be further enhanced with an inner bib that tucks into the wearer's shirt or coverall. Knitted and inflatable neck cuffs are not as dependent upon user behavior as other hood-style respirators with a body seal which relies on a draw string that the user tightens.

Despite the controversy surrounding continuous-flow class supplied-air respirators, surprisingly little research has been performed on the class. It is the author's hope that this study will spark additional interest among researchers and regulators so that the capabilities of this respirator class may become better understood.

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